

Model Analyzer.

What can I extract from a presolved optimization model?

COMILLAS
UNIVERSIDAD PONTIFICIA

ICAI ICADE CIHS

Andrés Ramos, Francisco Labora

<https://www.iit.comillas.edu/aramos/>

Andres.Ramos@comillas.edu

Contents

1. Introduction
2. Insights
3. Case studies



1

Introduction

COMILLAS
UNIVERSIDAD PONTIFICIA

ICAI

ICADE

CIHS

Motivation

*To Infinity
and beyond*



- The most powerful solvers have powerful presolve routines.
- **Presolve**: techniques that substantially reduce the dimensions (constraints, variables) or strengthen the problem formulation.
- How can I **improve the formulation of an optimization model** by comparing the mathematical formulation before and after presolve?
- Insights:
 - Can some **constraints** be **discarded**? Can they be considered **lazy**?
 - Are they **superfluous** variables?
 - Are **particular cases** considered in the model formulation?

Procedure

- Save the **LP file** from the original model and from the presolved one
- Extract for every **constraint** before and after presolve
 - Name, stem, sense, level, bound, dual variable
- Extract for every **variable** before and after presolve
 - Name, stem, type, lower bound, level, upper bound, reduced cost, range

ICAI ICADE CIHS

<https://github.com/IIT-EnergySystemModels/Fixed-Charge-Transportation-Problem-Benders-Decomposition/blob/main/ModelAnalyzer.py>

(Unexpected) tips from presolve

- There are variables whose **upper bound increases** after presolve
- **New variables** may also be added by presolve
- Some **equalities** before presolve are **changed to inequalities** after presolve
- All **$\geq$ inequalities changed to $\leq$** by presolve

Metrics

- Numerical tolerances

- Dual variable =0 if $|dual\ variable| < 1e - 6$
- Reduced cost =0 if $|reduced\ cost| < 1e - 6$

- Differences are calculated as the absolute value of the difference between absolute values of dual variables (reduced costs)

ICAI ICADE CIHS

Metrics for constraints

- **Bound** before and after presolve
- **Constraint bound reduction for $\leq$** only for **non-removed constraints**
$$1 - \frac{\text{constraint bound after presolve}}{\text{constraint bound before presolve}}$$
- **Constraint bound reduction for $\geq$** only for **non-removed constraints**
$$1 - \frac{\text{constraint bound before presolve}}{\text{constraint bound after presolve}}$$
- **Active** (binding) if equality or inequality is satisfied as **=**
- Number of **dual variables $\neq 0$**
- **Difference in dual variables** for the non-removed constraints

Metrics for variables

- **Range** before and after presolve
- **Variable range reduction** for **non-removed variables**
$$1 - \frac{\text{variable range after presolve}}{\text{variable range before presolve}}$$
- Number of **reduced costs** $\neq 0$
- **Difference in number of reduced costs** for the non-removed variables
- **Reduced costs** before and after presolve
 - Impact in the o.f. for moving the variable out of its bounds
- **Difference in reduced costs** for the non-removed variables
- **Proportion of variables** $= 0$ before and after presolve

2

Insights

COMILLAS
UNIVERSIDAD PONTIFICIA

ICAI

ICADE

CIHS



Insights about constraints

- Dual variables do not necessarily coincide before and after presolve → multiple dual solutions
- Non-binding removed equalities are instrumental
- All the removed inequalities are superfluous (in the optimum, all they have dual var =0)
- For non-removed inequalities, if the proportion that are binding in the optimal is very low (<5%), they could be declared lazy

Insights about variables

- **Reduced costs do not necessarily coincide** before and after presolve → multiple primal solutions
- All removed variables that only appear in inequalities or instrumental equalities are set at one of their bounds (with reduced cost $\neq 0$) or at an intermediate value (with reduced cost $=0$)

2

Case studies

ICAI

ICADE

CIHS

Constraints. Case SEP2025

ConstraintStem	R	R_ps	#RemovedR	%RemovedR	Bound	Bound_ps	%BoundReduction	#Active	#Dual	#Active_ps	#Dual_ps	#DiffDual	Dual	Dual_ps	DiffDual
c_e_eBalanceElec_2025_CY2018_st1	34944	13104	21840	62.50%	11.51103475	28.48074375		34944	30142	13104	13104	535	0.131555868	0.132477575	0.038371742
c_e_eSSInventory_2025_CY2018_st1	174720	170007	4713	2.70%	0.362143982	0.339868166		174720	174556	169845	169844	878	-0.078912987	-0.078516011	0.009218639
c_e_eSSTotalCharge_2025_CY2018_st1	122304	0	122304	100.00%	0	0		122304	20365	0	0	0	0.003514508	0	0
c_e_eEnergyOutflows_2025_CY2018_st1	416	416	0	0.00%	4.478787203	4.478787203		416	416	416	416	2	0.058488096	0.0584881	0.000477631
c_e_eHydroInventory_2025_CY2018_st1	39312	39272	40	0.10%	0.139075357	0.124813737		39312	39312	39272	39272	24	-0.03544516	-0.03547341	3.05017E-05
c_e_eKirchhoff2ndLaw1_2025_CY2018_st1	26208	0	26208	100.00%	0	0		26208	0	0	0	0	0	0	0
c_e_eOperReserveUp_2025_CY2018_st1	4368	4368	0	0.00%	0.690224107	0.690224107		4368	4368	4368	4368	32	0.008438581	0.008438156	0.000428819
c_e_eTotalCCost_2025_CY2018_st1	4368	0	4368	100.00%	0	0		4368	4368	0	0	0	1	0	0
c_e_eTotalEmissionArea_2025_CY2018_st1	4368	0	4368	100.00%	0	0		4368	0	0	0	0	0	0	0
c_e_eTotalGCost_2025_CY2018_st1	4368	0	4368	100.00%	0	0		4368	4368	0	0	0	1	0	0
c_e_eTotalOutput_2025_CY2018_st1	508644	235872	272772	53.63%	0.197560573	0.037037037		508644	293984	235872	203770	168925	0.004939519	0.014389375	0.012787086
c_e_eTotalRCost_2025_CY2018_st1	4368	0	4368	100.00%	0	0		4368	4368	0	0	0	0.000920146	0	0
c_e_eTotalTCost_	1	0	1	100.00%	0	0		1	1	0	0	0	1	0	0
c_e_eUCStrShut_2025_CY2018_st1	262080	250376	11704	4.47%	3.43407E-05	0		262080	187905	250376	210296	202142	-0.003798892	-0.012201842	0.016865572
c_l_eMinCharge_2025_CY2018_st1	8736	8736	0	0.00%	0	-8.40819E-07	100.00%	8683	8683	8363	8363	6342	0.008369313	-0.008480929	0.002220029
c_l_eMinOutput2ndBlock_2025_CY2018_st1	480480	0	480480	100.00%	0	0		193626	193626	0	0	0	0.039127224	0	0
c_l_eRampUpChr_2025_CY2018_st1	13104	0	13104	100.00%	-1	0		0	0	0	0	0	0	0	0
c_u_eChargeDischarge_2025_CY2018_st1	109200	100464	8736	8.00%	1	1	0.00%	3081	3081	6583	6583	5401	-6.37365E-05	-0.000280537	0.00449043
c_u_eMaxCharge_2025_CY2018_st1	21840	21840	0	0.00%	0	0.400002038		3726	3726	17470	8874	7095	-0.000418442	-0.000537164	0.000991332
c_u_eMaxOutput2ndBlock_2025_CY2018_st1	480480	292605	187875	39.10%	0.372727273	0.029855949	0.00%	142600	142600	122110	122072	164309	-0.001471459	-0.008214036	0.015960892
c_u_eMaxSystemEmission_2025_CY2018_st1	1	0	1	100.00%	9999	0		0	0	0	0	0	0	0	0
c_u_eMinDownTime_2025_CY2018_st1	17460	17460	0	0.00%	1	1	0.00%	0	0	2	2	2	0	-1.29647E-07	0.001131815
c_u_eMinUpTime_2025_CY2018_st1	17460	17460	0	0.00%	0	0		336	336	1258	1258	1566	-0.000347994	-0.002911426	0.03574464
c_u_eRampDwChr_2025_CY2018_st1	13104	0	13104	100.00%	1	0		0	0	0	0	0	0	0	0
c_u_eRampDw_2025_CY2018_st1	59280	18696	40584	68.46%	1	1	0.00%	239	239	17702	501	266	-1.86031E-05	1.36361E-05	0.00520095
c_u_eRampUp_2025_CY2018_st1	59520	1357	58163	97.72%	1	1	0.00%	275	275	12	12	0	-2.37576E-05	-1.12379E-05	0
c_u_eTrbReserveUpIfDownstream_2025_CY2018_st1	13104	13101	3	0.02%	5122.341176	5123.262365	0.00%	126	126	126	126	3	-3.59648E-06	-3.37758E-06	0.000959543
c_u_eTrbReserveUpIfUpstream_2025_CY2018_st1	13104	13088	16	0.12%	-536.9360157	-536.5838873	0.00%	70	70	68	68	15	-4.48848E-06	-1.43108E-06	0.002792106

Insights for constraints

- Inequalities $eRampUpChr$, $eRampDwChr$, $eRampDw$ are removed
- Almost all $eRampUp$ inequalities are removed
- All $eESSTotalCharge$ and $eKirchhoff2ndLaw1$ constraints are removed
- Equality (instrumental) constraints ($eTotalCCost$, $eTotalEmissionArea$, $eTotalGCost$, $eTotalRCost$, $eTotalTCost$) are removed

ICAI

ICADE

CIHS

Variables. Case SEP2025

VariableStem	C	C_ps	#RemovedC	%RemovedC	Range	Range_ps	%RangeReduction	#RC	#RC_ps	#DiffRC	RC	RC_ps	DiffRC
vCharge2ndBlock	122304	4368	117936	96.43%	0.045	0.045	0.00%	11936	4368	3366	0.003745439	0.156552191	0.199933015
vCommitment	301392	263540	37852	12.56%	1	1.000066297	-0.01%	69783	117022	146531	0.005506197	-0.014095821	0.077437239
vCommitmentCons	21840	13104	8736	40.00%	1	1.000666514	-0.07%	7750	6002	9482	-8.34105E-05	0.000673986	0.001764956
vENS	21839	12835	9004	41.23%	28.86065773	28.86065773	0.00%	9170	12835	12835	0.036150154	199.8647861	199.8125682
vESSInventory	174680	169968	4712	2.70%	296.880226	296.8869185	0.00%	1489	1391	597	1.45562E-06	1.32176E-06	0.007167739
vESSReserveDown	8736	0	8736	100.00%	0	0		8218	0	0	0.00781776	0	0
vESSReserveUp	8736	8736	0	0.00%	0.105	0.105	0.00%	54	445	495	-7.90818E-05	0.000410377	0.020165797
vESSSpillage	174720	0	174720	100.00%	0	0		174556	0	0	0.07891408	0	0
vESSTotalCharge	122304	117933	4371	3.57%	0.633632337	0.633632337	0.00%	81036	87400	21013	0.031171463	0.031256956	0.035705244
vEnergyOutflows	8736	8734	2	0.02%	1.339265631	1.33928853	-0.02%	393	495	181	0.003482325	0.003837935	0.021125384
vFlowElec	30576	0	30576	100.00%	0	0		18835	0	0	0.008104531	0	0
vOutput2ndBlock	480480	312545	167935	34.95%	0.563895767	0.563925774	-0.04%	23255	272700	268533	-0.001985119	0.081826918	0.098576244
vReserveUp	244608	244557	51	0.02%	0.283389972	0.283389972	0.00%	115405	151949	144021	0.007075947	0.013840275	0.029163276
vReservoirSpillage	39312	34908	4404	11.20%	inf	inf	100.00%	34756	30388	35	0.010204276	0.010247281	2.70111E-05
vReservoirVolume	39303	39301	2	0.01%	211.8462846	211.8462846	0.00%	488	495	18	1.57802E-06	2.82533E-06	0.003628037
vShutDown	301383	261969	39414	13.08%	1	1	0.00%	143741	206580	210225	0.005636112	0.021335656	0.022619893
vStartUp	301392	262020	39372	13.06%	1	1	0.00%	181816	88693	179142	0.008408649	0.00818864	0.017035295
vTheta	26208	0	26208	100.00%	0	0		0	0	0	0	0	0
vTotalCCost	4368	0	4368	100.00%	0	0		0	0	0	-2.92058E-14	0	0
vTotalECost	4368	0	4368	100.00%	0	0		4368	0	0	1	0	0
vTotalEmissionArea	4368	0	4368	100.00%	0	0		0	0	0	0	0	0
vTotalGCost	4368	0	4368	100.00%	0	0		0	0	0	0	0	0
vTotalICost	1	0	1	100.00%	0	0		1	0	0	1	0	0
vTotalOutput	563229	447050	116179	20.63%	0.804964199	0.852235621	-41.61%	329660	199151	206970	0.020055069	0.026254974	0.079385803
vTotalRCost	4368	0	4368	100.00%	0	0		4368	0	0	0.999079854	0	0
vTotalSCost	1	0	1	100.00%	0	0		0	0	0	0	0	0

Insights for variables

- Almost all *vCharge2Block* variables are removed. Check which ones remain
- Most variables with infinity UB (e.g., reservoir spillage *vESSSpillage*) disappear
- Voltage angles *vTheta* are removed (case with 8 nodes)
- Instrumental variables (*vTotalCCost*, *vTotalECost*, *vTotalGCost*, *vTotalICost*, *vTotalRCost*, *vTotalSCost*) are removed
- Ranges are only slightly modified
- Range decreases for *vEnergyOutflows* and increases for *vTotalOutput*

Constraints. Case NT2030

ConstraintStem	R	R_ps	#RemovedR	%RemovedR	Bound	Bound_ps	%BoundReduction	#Active	#Dual	#Active_ps	#Dual_ps	#DiffDual	Dual	Dual_ps	DiffDual
c_e_eBalanceElec_2030_Scen1_st1	655200	559875	95325	14.55%	7.884990731	7.471294094		655200	568285	559467	535262	9	1.79057475	0.087621249	0.002629659
c_e_eESSInventory_2030_Scen1_st1	1354080	1353390	690	0.05%	-0.263952278	0.087947704		1354080	1353327	1352637	1352637	27835	0.054760484	-0.054840379	0.00670365
c_e_eESSTotalCharge_2030_Scen1_st1	995904	0	995904	100.00%	0	0		995904	407745	0	0	0	0.003504755	0	0
c_e_eEnergyOutflows_2030_Scen1_st1	288288	0	288288	100.00%	0.826898649	0		288288	288288	0	0	0	0.025549769	0	0
c_e_eTotalCCost_2030_Scen1_st1	8736	0	8736	100.00%	0	0		8736	8736	0	0	0	1	0	0
c_e_eTotalECostArea_2030_Scen1_st1	393120	0	393120	100.00%	0	0		393120	393120	0	0	0	0.94594379	0	0
c_e_eTotalECost_2030_Scen1_st1	8736	0	8736	100.00%	0	0		8736	8736	0	0	0	1	0	0
c_e_eTotalGCost_2030_Scen1_st1	8736	0	8736	100.00%	0	0		8736	8736	0	0	0	1	0	0
c_e_eTotalOutput_2030_Scen1_st1	4205055	0	4205055	100.00%	0.037394992	0		4205055	1112936	0	0	0	-0.005876807	0	0
c_e_eTotalRCost_2030_Scen1_st1	8736	0	8736	100.00%	0	0		8736	8736	0	0	0	0.254641672	0	0
c_e_eTotalTCost	1	0	1	100.00%	0	0		1	1	0	0	0	1	0	0
c_e_eUCStrShut_2030_Scen1_st1	1085192	0	1085192	100.00%	0.000925182	0		1085192	881	0	0	0	-4.35684E-08	0	0
c_u_eChargeDischarge_2030_Scen1_st1	698880	689399	9481	1.36%	1	1	0.00%	3	3	7	7	6	-4.40078E-11	-4.84093E-11	6.05868E-06

Insights for constraints

- All *eESSTotalCharge* constraints are removed
- All *eEnergyOutflows* constraints removed due to hourly OutflowsType that fixes *vEnergyOutflows* variable to the outflows profile
- All *eTotalOutput* constraints are removed because there are no minimum load and therefore $vTotalOutput = vOutput2ndBlock$

Variables. Case NT2030

VariableStem	C	C_ps	#RemovedC	%RemovedC	Range	Range_ps	%RangeReduction	#RC	#RC_ps	#DiffRC	RC	RC_ps	DiffRC
vCharge2ndBlock	995904	45	995859	100.00%	1	1	0.00%	407742	0	0	0.003504755	0	0
vCommitment	1085192	42870	1042322	96.05%	1	4.634111375	-363.41%	929621	23877	2466	-0.004944688	0.035082111	0.03029488
vENS	550368	403874	146494	26.62%	7.199267336	7.818843089	-727.59%	540013	403861	299906	125.2165314	499.9275731	499.8791348
vESSInventory	1353925	1353235	690	0.05%	1259.966411	1259.967176	0.00%	32110	31969	6516	1.33284E-06	1.33352E-06	0.005262121
vESSSpillage	1354080	0	1354080	100.00%	0	0		1353327	0	0	0.054760484	0	0
vESSTotalCharge	995904	995859	45	0.00%	1.912808228	1.912808228	0.00%	302261	708328	414494	0.037926504	0.041321285	0.011823571
vEnergyOutflows	288288	0	288288	100.00%	0	0		0	0	0	0	0	0
vFlowElec	1275456	1055001	220455	17.28%	3.099063107	3.219485289	-6.09%	503926	371378	230	0.894616535	0.021041514	0.042688785
vOutput2ndBlock	3547927	276403	3271524	92.21%	1.967928563	2.12480344	-16.21%	529822	240468	9364	-0.002845622	-0.003967855	1.035126622
vShutDown	1085192	0	1085192	100.00%	0	0		881	0	0	4.35684E-08	0	0
vStartUp	1085192	0	1085192	100.00%	0	0		881	0	0	-4.35684E-08	0	0
vTotalCCost	8736	0	8736	100.00%	0	0		0	0	0	0	0	0
vTotalECost	8736	0	8736	100.00%	0	0		0	0	0	0	0	0
vTotalECostArea	401856	0	401856	100.00%	0	0		25205	0	0	0.074620206	0	0
vTotalGCost	8736	0	8736	100.00%	0	0		0	0	0	0	0	0
vTotalICost	1	0	1	100.00%	0	0		1	0	0	1	0	0
vTotalOutput	5627223	3816193	1811030	32.18%	1.444502586	1.852822532	-771.48%	3577266	3039061	767677	-1.120905716	-0.007068353	0.043499251
vTotalRCost	8736	0	8736	100.00%	0	0		6513	0	0	0.745358328	0	0
vTotalSCost	1	0	1	100.00%	0	0		0	0	0	0	0	0

Insights for variables

- *vEnergyOutflows* variables fixed to the outflow profile due to hourly OutflowsType
- All *vShutDown*, *vStartUp* and most of the *vCommitment* variables removed because there are no startup or shutdown costs

Constraints. Case UG2030

ConstraintStem	R	R_ps	#RemovedR	%RemovedR	Bound	Bound_ps	%BoundReduction	#Active	#Dual	#Active_ps	#Dual_ps	#DiffDual	Dual	Dual_ps	DiffDual
c_e_eBalanceElec_2030_sc01_st1	742560	680587	61973	8.35%	0.012476806	0.013612921		742560	14	680587	2858	2861	4.21306E-06	3.60217E-05	0.006087469
c_e_eKirchhoff2ndLaw1_2030_sc01_st1	838656	0	838656	100.00%	0	0		838656	0	0	0	0	0	0	0
c_e_eLineStateCand_2030_sc01_st1	838656	0	838656	100.00%	0	0		838656	84	0	0	0	-9.37638E-05	0	0
c_e_eTotalCCost_2030_sc01_st1	8736	0	8736	100.00%	0	0		8736	8736	0	0	0	1	0	0
c_e_eTotalFCost	1	0	1	100.00%	0	0		1	1	0	0	0	1	0	0
c_e_eTotalGCost_2030_sc01_st1	8736	0	8736	100.00%	0	0		8736	8736	0	0	0	1	0	0
c_e_eTotalICost	1	0	1	100.00%	0	0		1	1	0	0	0	1	0	0
c_e_eTotalOutput_2030_sc01_st1	34944	0	34944	100.00%	0	0		34944	31	0	0	0	5.36716E-06	0	0
c_e_eTotalRCost_2030_sc01_st1	8736	0	8736	100.00%	0	0		8736	8736	0	0	0	1	0	0
c_e_eTotalTCost	1	0	1	100.00%	0	0		1	1	0	0	0	1	0	0
c_l_eAdequacyReserveMarginElec_2030_sc01_st1	1	1	0	0.00%	0.082539186	-0.082539186	0.00%	1	1	1	1	0	108.2033333	-108.2033333	0
c_u_eInstallGenCap_2030_sc01_st1	596763	596763	0	0.00%	0	0		0	0	0	0	0	0	0	0
c_u_eKirchhoff2ndLaw1_2030_sc01_st1	838656	803712	34944	4.17%	1	0.956521184	4.35%	0	0	0	0	0	0	0	0
c_u_eKirchhoff2ndLaw2_2030_sc01_st1	838656	838656	0	0.00%	1	1.083333866	-8.33%	0	0	0	0	0	0	0	0
c_u_eLineLosses1_2030_sc01_st1	1677312	1624748	52564	3.13%	0	-8.07604E-10		2	2	833	833	835	-7.21392E-09	-5.70644E-06	0.011118121
c_u_eLineLosses2_2030_sc01_st1	1677312	1659826	17486	1.04%	0	-5.20272E-06		7	7	12	12	15	-1.45252E-05	-4.93151E-06	1.088429621
c_u_eNetCapacity1_2030_sc01_st1	838656	838656	0	0.00%	0	-7.98619E-07		18	18	3092	3092	3094	-2.32299E-06	-6.09857E-06	0.00105804
c_u_eNetCapacity2_2030_sc01_st1	838656	838656	0	0.00%	0	7.98619E-07		6	6	1232	1232	1230	-1.90216E-06	-3.63762E-06	0.001185884

Insights for constraints

- Equality constraints *eKirchhoff2ndLaw1* (*flow = angle difference*) are instrumental for existing lines
- All *eTotalOutput* constraints are removed because there are no minimum load and therefore *vTotalOutput* = *vOutput2ndBlock*

Variables. Case UG2030

VariableStem	C	C_ps	#RemovedC	%RemovedC	Range	Range_ps	%RangeReduction	#RC	#RC_ps	#DiffRC	RC	RC_ps	DiffRC
vENS	325627	275057	50570	15.53%	0.032305706	0.036492181	-66.65%	0	8	8	0	-1.77741E-07	0.006111111
vFlowElec	1677312	872779	804533	47.97%	0.360914804	0.360914804	0.00%	0	0	0	0	0	0
vGenerationInvest	73	73	0	0.00%	1	1	0.00%	71	71	0	3.495863677	3.495863677	0
vLineCommit	838656	0	838656	100.00%	0	0		64	0	0	8.95387E-05	0	0
vLineLosses	1677312	1677312	0	0.00%	0.002995559	0.003066204	-3.99%	25	8331	8340	7.58678E-06	6.24947E-05	0.011081981
vNetworkInvest	96	96	0	0.00%	1	1	0.00%	24	88	69	0.395114751	1.129179988	1.061992176
vOutput2ndBlock	34944	0	34944	100.00%	0	0		31	0	0	5.36716E-06	0	0
vTheta	733824	637728	96096	13.10%	3.141592654	inf	-inf	0	0	0	0	0	0
vTotalCCost	8736	0	8736	100.00%	0	0		0	0	0	0	0	0
vTotalECost	8736	0	8736	100.00%	0	0		8736	0	0	1	0	0
vTotalFCost	1	0	1	100.00%	0	0		0	0	0	0	0	0
vTotalGCost	8736	0	8736	100.00%	0	0		0	0	0	0	0	0
vTotalICost	1	0	1	100.00%	0	0		0	0	0	0	0	0
vTotalOutput	982951	751307	231644	23.57%	0.026285445	0.032096413	-143.63%	34916	34087	893	0.000315397	0.000405965	0.00605
vTotalRCost	8736	0	8736	100.00%	0	0		0	0	0	0	0	0
vTotalSCost	1	0	1	100.00%	0	0		0	0	0	0	0	0

Insights for variables

- *vLineCommit* variables removed, are equal to *vNetworkInvest* due to *eLineStateCand* constraint (*line commitment = line investment*)
- All *vOutput2ndBlock* variables are removed because there are equal to *vTotalOutput*

Thank you for your attention

Andrés Ramos, Francisco Labora

<https://www.iit.comillas.edu/aramos/>

Andres.Ramos@comillas.edu